A Mobile Robot for Remote Response to Incidents Involving Hazardous Materials

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Abstract

First entry into situations where hazardous materials have been accidently spilled or released is extremely dangerous. Often the type of material, its exact location, and the extent of the spill is unknown. Mobile robots provide a means to safely explore an incident site locating the hazard as well as aiding in its identification and mitigation. This paper will describe a teleoperated mobile robot system being developed at JPL (Jet Propulsion Laboratory) for use by the JPL Fire Department/HAZMAT (hazardous material) Team. The project, which began in October 1990, is focused on prototyping a robotic vehicle which can be quickly deployed and easily operated by HAZMAT Team personnel allowing remote entry and exploration of a hazardous material incident site.

The close involvement of JPL Fire Department personnel has been critical in establishings ystem requirements as well as evaluating the system. The current robot, called HAZBOT III, has been specially design for operation in environments that may contain combustible gases. Testing of the system with the Fire Department has shown that teleoperated robots can successfully gain access to incident sites allowing hazardous material spills to be remotely located and identified. Work is continuing to enable more complex missions through enhancement of the operator interface and by allowing tetherless operation.

J.0 Introduction

Responding to incidents involving hazardous materials can be extremely dangerous and requires specially trained HAZMAT personnel. Upon arrival to an incident site, the HAZMAT team must first try to determine what types of

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materials are involved and what threat they present. Unfortunately; records may not be complete or easily accessible and the only way to determine the type and extent of the hazard is to send in HAZMAT Team personnel.

First entry into an incident site where the type of materials involved have not been identified is particularly dangerous. Members of the team must take all precautions and wear full protective gear including a self contained breathing apparatus and a multi-layer protective suit. This type of protective gear significantly restricts mobility, allows at most 45 minutes activity, and can be extremely hot and stressful on the wearer. Moreover it can take up to an hour for the entry team to suit up once it has arrived at the incident sight delaying identification of the hazard.

The Emergency Response Robotics project at JPL is developing a mobile robot system that can be quickly deployed by HAZMAT teams and allow remote reconnaissance into an incident site without risk to team personnel. The primary goals of the project are:

- Develop a teleoperated mobile robot system which can be easily operated by HAZMAT Team personnel allowing remote access to an incident site (which may require climbing stairs, unlocking/opening doors, and operating in confined spaces), identification of chemical spills via visual inspection and remote chemical sensing, as well as aid in incident mitigation/containment.
- Work directly with the end-user of such as ystem (JPL Fire Department/ HAZMAT Team) to establish system requirements as well as operate and critique the system under development.

These initial goals of the project are discussed in detail in [Stone 91]. Other examples of the application of robotics to hazardous material operations are given in [Meieran 89, 90 and Roy 89].

Several commercially available robotic vehicles were evaluated and two REMOTEC[2] ANDROS Mark V-A systems were procured. (A reference book which covers many of the commercially available and research robots for hazardous operations is [Brittain 90].) The ANDROS robot has a variety of important features including its rugged construction, track drive system enabling stair climbing, manipulator, on-board battery power, and sufficient size to support addition of equipment. Communication between the robot and operator control station is achieved by a 100m tether.

The next section briefly describes the modifications to the ANDROS robot undertaken in the first year of the project (October 1990 through September 1991) leading to the HAZBOT II system. (The name HAZBOT I being given to the "as purchased" system.) The section following this discusses the development of

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[2]REMOTEC, 114 Union Valley Road, Oak Ridge, TN 37830

HAZBOT III, a major rebuild of the ANDROS system. Finally, the current status of the project and future plans are presented.

2.0 HAZBOT 11

The most important factor in the development of the HAZBOT 11 system was training and experimentation with the JPL Fire Department and HAZMAT Team to determine their requirements. This testing revealed the need for several modifications. One of the most important was the redesign of the operator control panel. The control panel supplied with the system used an array of simple toggle switches to actuate a joint in the robot manipulator. For example, one switch was labeled elbow up/down. This type of control was very difficult for the trainees to master because whether or not the elbow joint caused the forearm of the manipulator to actually move up or down was dependent on the current position or configuration of the manipulator. A new control panel was therefore constructed that used a simple side view graphic of the robot with controls for each joint placed at the corresponding point of the drawing. The toggle switches where replaced with spring loaded potentiometers; for instance, rotation of the elbow potentiometer clockwise caused the elbow joint to also rotate clockwise. This system was found much more intuitive for the Fire Department personnel and led to far fewer mistakes during manipulation tasks.

The HAZBOT II system included a variety of other experimental modifications such as: specialized key tools for unlocking doors; placement of the pan/tilt camera on movable boom allowing better viewing angles during manipulation tasks; integration of a commercial combustible gas sensor often used by HAZMAT teams; and addition of a laser depth cuing system. These modifications are described in greater detail in [Stone 92].

At the end of the first year of the project, a simulated HAZMAT reconnaissance mission was carried out by the JPL Fire Department using HAZBOT II. The mission (described in [Stone 92]) included: opening the outside door of incident site building which had a thumb latch style handle; navigating to chemical storeroom in building; unlocking and opening storeroom door as shown in Figure 1; and operation in the very small storeroom locating a simulated chemical spill.

Although the use of mobile robots in HAZMAT operations was shown feasible by this first year demonstration a variety of issues were identified that must be addressed for the system to be used in real response missions:

- Redesign of the robot so that it can operate in an environment that may contain combustible gases with little risk of igniting those gases. This is particularly important in first entry situations where the type of hazard is unknown and potentially combustible.

- Redesign of robot with smooth profile and appropriate sealing so that is can be easily decontaminated after a mission.
- Improvement of manipulator in terms of speed and dexterity.
- Continued enhancement of the operator controls.
- Addition of tetherless operation to allow deployment of vehicle greater than 100m from incident site.

The next section describes how these requirements and the lessons learned in the first year of the project have been used to develop the HAZBOT III system.

3.0 HAZBOT III

The focus of the second year of the project was to significantly redesign the HAZBOT I robot (that had not been modified in the first year) to meet the system

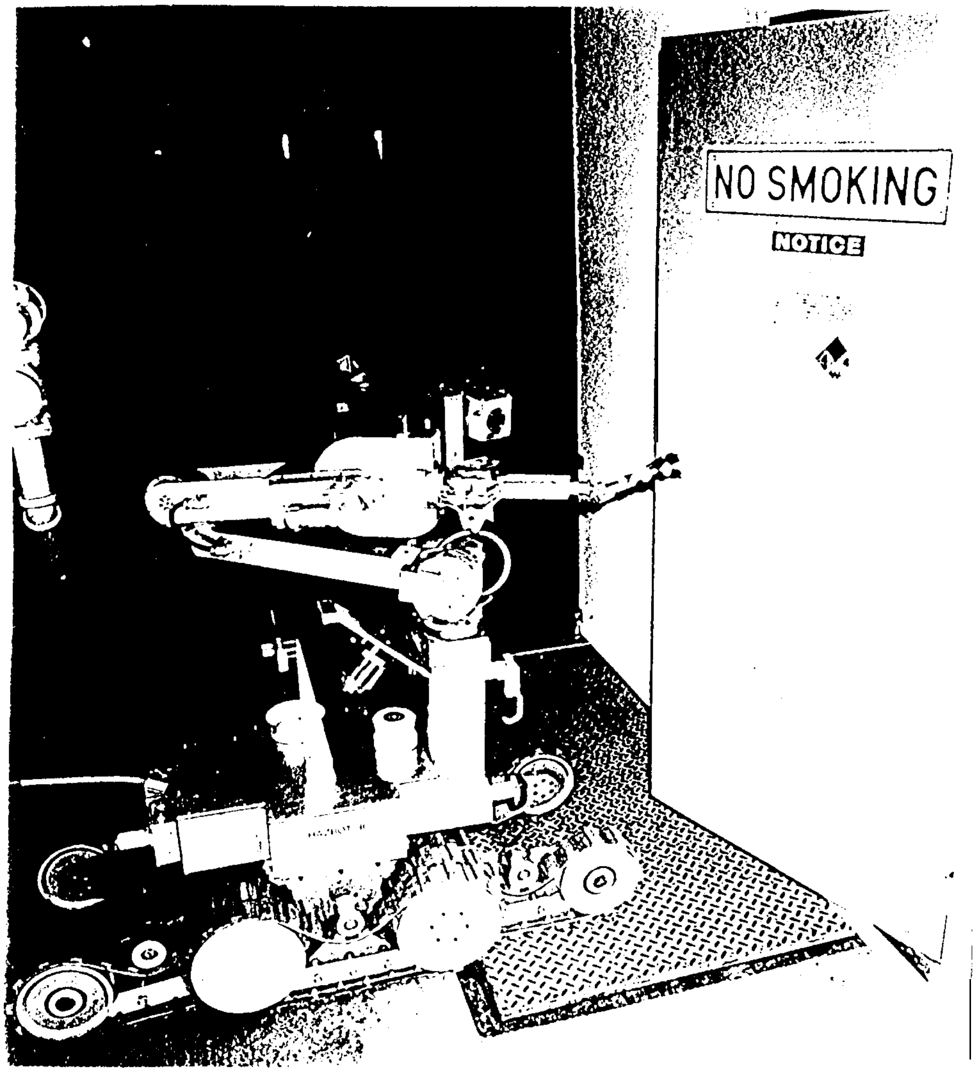

Figure 1 Hazbot 11 Unlocking Chemical Storeroom Door

requirements enumerated in the previous section. The key driver in design of the new system was the need for operation in a potentially combustible environment. A two tiered approach was used to address this design requirement. First, all electrical components that may cause electrical arcs or sparks during normal operation were replaced with solid state devices. This included using solid state relays instead of mechanical relays and replacing the brushed DC motors with brushless motors. As a second precaution, all areas of the robot that contain electrical components that could fail and cause sparks are pressurized. The system was not designed to be hermetically sealed but rather to support a small pressure above atmospheric so not to allow any combustible vapors to enter the system.

The rebuilt system, called HAZBOT III, is shown in Figure 2. One of the most significant changes in appearance from HAZBOT II is the new 6 DOF manipulator (the original REMOTEC manipulator was 5 DOF) which incorporates the following features:

- Smooth profile to ease decontamination and reduce possible of snagging during manipulation tasks.
- Internal channels to support pressurization up to and including gripper.
- Provisions for two movable booms on torso (one currently being used for pan/tilt camera) which also includes channels for pressurization.

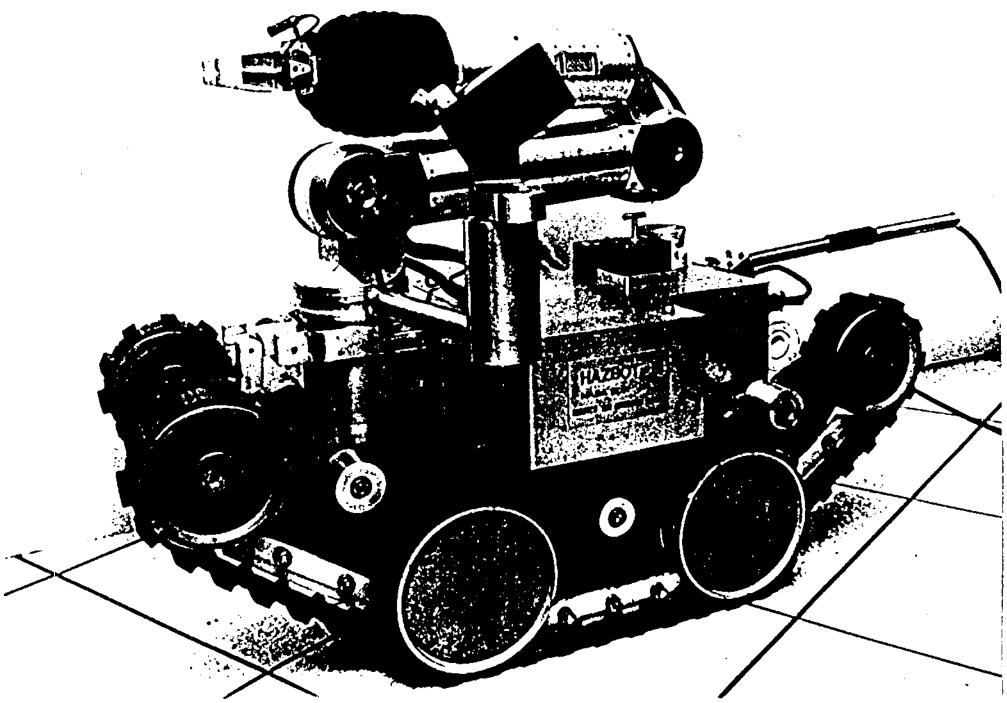

Figure 2 The HAZBOT III Robot

- ARoss-HimeDesigns33 DOF OMNI-Wrist.
- An AIM 3300[4] specific gas and general combustible gas sensor integrated into forearm and drawing samples in through tip of gripper.
- A wrist mounted camera to aid in manipulation tasks.
- Increases of up to 7.5 times in joint speed and significant reduction in backlash through the use of harmonic drives.

Other important features of HAZBOT 111 include a winch system which can be deployed by the manipulator, a microphone and speaker allowing 2-way audio communication, and a front mounted tool holder.

The chassis of the vehicle was also enlarged to house a VME type computer system and control electronics. The original ANDROS vehicle used a simple computer system with open loop control of the manipulator. The new VME system includes a 68030 CPU, closed loop control of the new 6 axis manipulator, a variety of analog and digital 1/0, as well as room for expansion. Software has been developed using the VxWork[5] real-time operating system. This computer system provides a solid foundation for future development in coordinated manipulator motion, automation of sub-tasks such as tool retrieval/storage, as well as remote sensing.

A VME computer similar to the one described above was also used on the operator control station. In this case thes ystem reads and interprets analog and digital inputs from the switches and potentiometers on the control panel and transmits corresponding commands to HAZBOT III. The robot receives and carries out these commands as well as transmits status information back to the control station including the chemical data collected with the AIM gas sensor,

In early 1993, HAZBOT III was used to perform a second simulated HAZMAT mission in conjunction with the JPL Fire Department. The mission, carried out in the waste material storage facility at JPL, was modeled after an actual incident which had occurred at the site a year earlier. The mission included:

- Unlocking and opening an exterior gate to the facility.
- Locating a simulated spill through an inspection window in storeroom door.
- Unlocking and opening the door to the storeroom as shown in Figure 3 (utilizing the same keytool used to unlock gate).
- Deployment of absorbent pads on spill.
- Opening of cabinet from where a chemical was leaking.

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[3]Ross-Hime Designs, Minneapolis, MN 55414

[4]AIM USA, Houston, TX 77272

‘Wind River Systems, Alameda, CA 94501

- Visual inspection and identification of broken container responsible for spill.

At the time this paper was written, the track drive sub-system is being upgraded with brushless motors and the pressurization system tested to complete the system rebuild for operation on combustible environments. Training and experimentation of HAZB OT III by the Fire Department will continue and help identify areas for continued development. In late 1993 another simulated response mission is planned. This will include decontamination of the robot after the mission, a necessity for real HAZMAT operations,

4.0 Future Plans

The HAZBOT III system has addressed many of the requirements as defined by the Fire Department and project team. Two important issues which will be addressed over the next year of the project are:

- Tetherless operation - Depending on the type of incident, the robot may have to be deployed at a distance to the incident site greater than its 100m tether length. Also, complex site entry with multiple doors, stairs, etc. increase the chance of snagging the tether and delaying or ending the mission. The tether

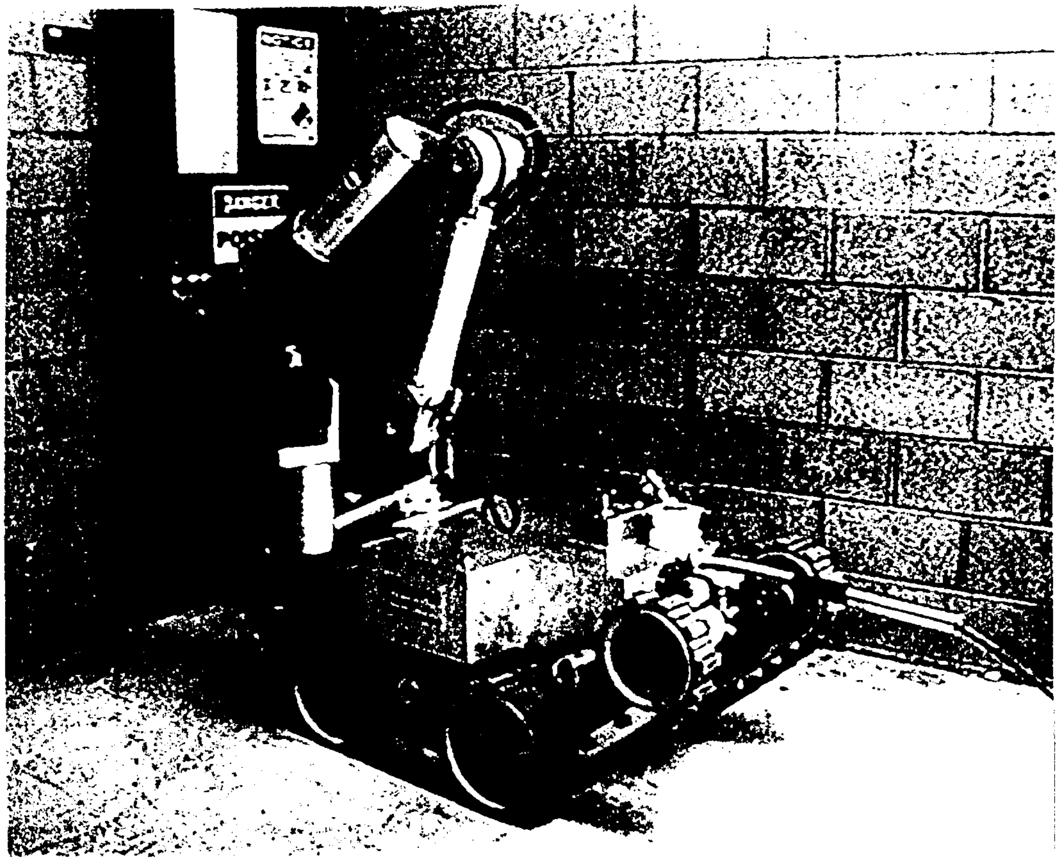

Figure 3 HAZBOT III Unlocking Storeroom Door

will be replaced by an RF link for two video signals, 2-way audio, and 2-way data communication.

- Operator controls - The control panel developed in the first year of the project for HAZBOT 11 has also be used for HAZBOT III. Although a significant improvement from the original design, a wide variety of enhancements can be made to make the operators job easier. (Operator fatigue is a major problem in teleoperations.) These include control algorithm development for coordinated manipulator motion, automation of simple sub-tasks such as tool retrieval/storage, addition of a graphical display indicating system status, sensor data, and vehicle kinematics. (One of the most redundant tasks undertaken by the operator is verification of manipulator position/orientation by scanning with pan/tilt camera.) Additional sensors will also be added to provide information to the operator. It is important to note that the users of this system are not researchers or engineers but Fire Fighters. The controls and feedback to the operator must be in a form that makes sense to them and allows them to confidently use the system for HAZMAT operations.

5.0 Summary and Conclusion

This paper has described the Emergency Response Robotics project and the development of the HAZBOT robots at JPL. The project is developing a teleoperated mobile robot for use by the JPL Fire Department/HAZMAT Team in responding to incidents involving hazardous materials. Key features of the HAZBOT III system include:

- Operator control station with two video displays, custom control panel, and tether reel.
- Tracked mobility system with articulated front and rear sections allowing stairs to be traversed.
- Real-time computer system providing basis for future system development.
- Custom 6 DOF manipulator with integrated chemical gas sensor.
- System design for operation in combustible atmospheres by using non-arcing electrical components (brushless motors) and internal pressurization.

A critical factor in the system development is the close interaction of the project engineers with the JPL Fire Department and safety personnel, The two simulated response missions have shown that the HAZBOT system is capable of first entry/reconnaissance type missions. Continued development and training with the Fire Department will lead to a prototype system that they can use to respond to actual incidents involving hazardous materials thereby reducing the chance of injury or death of HAZMAT team personnel,

Acknowledgment

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Keywords

telerobotics, mobile robot, safety robot, remote vehicle, hazardous materials, HAZMAT